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AUTHOR Anderson, Ronald D.; And Others
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ABSTRACT

The University of Colorado, under contract with the Office of Educational Research and Improvement (OERI), is conducting a study of curriculum reform in science, mathematics, and higher order thinking across the disciplines. This paper provides some of the background for this research as well as information on the conceptual framework and design of the study. An extensive literature review made it clear that school sites with fully implemented reforms should not be expected to serve as subjects of the study, in that the reforms are generally too recent to be ready for investigation, and because sites should be studied from a systemic perspective. It is also essential that these sites be studied from multiple perspectives because of the complexity of curriculum reform efforts. The design of the case studies reflects the literature review conclusions, focusing on sites with reforms as fully implemented as possible, to be studied over time to illustrate the current reform process. An important aspect of this study is identifying critical events that embody or illustrate the reform effort whether successful or unsuccessful. Among the types of events sought are those including the classroom, the school, and the district, and guidelines for observation, questioning, and analysis of the events are provided. The bulk of the data is being acquired through site visits, augmented by printed materials and telephone interviews. An analysis of the reform systems is expected to be completed in the 1992-93 school year, with a follow-up as funding permits. (SLD)

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CONDUCTING CASE STUDIES OF CURRICULUM REFORM IN SCIENCE AND MATHEMATICS EDUCATION

Ronald D. Anderson
University of Colorado

Beverly L. Anderson
InSites, Inc.

Mary Ann Varanka Martin
University of Colorado

Lewis S. Romagnano
Metropolitan State College

February 13, 1993

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CONDUCTING CASE STUDIES OF CURRICULUM REFORM IN SCIENCE AND MATHEMATICS EDUCATION

Under a contract with the Office of Educational Research and Improvement of the U.S. Department of Education, the University of Colorado is conducting a study of curriculum reform in science, mathematics and higher order thinking across the disciplines. Begun in the fall of 1991, the project was contracted to continue until early 1995, although the appropriations bill passed in the last session of Congress has left funding of the family of projects to which this project belongs in a state of uncertainty. Nevertheless, three case studies are being pursued under the Curriculum Reform Project during the 1992-93 school year: one in mathematics, another in science and a third in which science is being integrated with English and social studies. (The authors of this paper with primary responsibility for each of these three cases are L.S. Romagnano, R.D. Anderson and B.L. Anderson, respectively.)

This paper provides some of the background for this research and information on the conceptual framework and design for the study. The background for this research is largely provided by an extensive literature review (Anderson, et al., 1992) which addressed the substance of curriculum reform in mathematics, science and higher order thinking across the disciplines, as well as the process of educational change. Some highlights of this review are presented below. The remainder of the paper describes the conceptual framework and design of the study.

HIGHLIGHTS OF THE LITERATURE REVIEW

Common Themes of the Reformers

The reviews of the research literature with respect to mathematics education, science education, and learning to think, have produced some common themes. The reader familiar with the literature in any one of these areas will recognize most of the common themes which were found in this look across curriculum areas.

Learning to think is an educational goal that extends across the disciplines with particular attention in the subject areas of science and mathematics. In contrast to some times in the past, it generally is regarded today as an essential goal for <u>all</u> students, not simply those going on to higher education. The research literature portrays this kind of thinking as being complex, not fully known in advance, often yielding multiple solutions, involving uncertainty, requiring nuanced judgments, and requiring considerable mental effort. It also must be done in a context; the subject matter of the school curriculum provides such a context. Students do not learn to think in the abstract;

they learn to think with subject matter. Science and mathematics provide an excellent place in the curriculum for students to learn to think.

A second theme of the research is what is commonly called a constructivist approach to teaching and learning. In this view of learning, students are not passive recipients of information. Learning requires active involvement of the student in constructing meaning. Rather than just receiving more information, the learner must negotiate meaning with his/her learning community, make connections with past personal understandings -- modifying these prior conceptions if they are not accurate -- and build understandings that are part of that person's personal conceptual framework. These new understandings occur in a learning community and pertain to particular contexts; attending to context is an important consideration in fostering learning in science and mathematics.

It is recognized that the implications of this conception of learning for classroom practice are many and that they are the subject of considerable discussion in the literature. Competing viewpoints exist but an analysis of alternatives is beyond the scope of this paper and the constructivist label will be used here in its more general sense.

If students are to construct the desired learnings new approaches are needed on the part of teachers. They must focus on helping students construct understanding of concepts for themselves. Instead of spending time memorizing material, filling in blanks on worksheets, and repeating large numbers of similar problems, students need to solve novel problems, integrate information and create knowledge for themselves. The teacher's role is to foster this hard work on the part of the student.

While the research indicates what such teaching involves, these findings are not as definitive as the findings pertaining to the learning itself; more is known about constructivist learning than constructivist teaching. In particular, this understanding of teaching is limited when considered in the context of classrooms having large numbers of students of diverse backgrounds and abilities.

A related theme often goes under the slogan, "less is more." Some information is more important than other information in developing this sophisticated understanding of science and mathematics. It is not just a matter of learning more, it is a matter of learning that which will help build the desired overall conceptual picture. Encyclopedic learning of large quantities of information potentially can interfere with this selective learning of that which is of fundamental importance -- especially given the fact that some of these most important understandings are the most complex and require the most effort to learn.

Effective learning requires focusing on the most important concepts and making the effort -- on the part of the learner -- required to build the necessary understanding. This greater selective attention to the most important conceptual understandings is the foundation of effective learning, thus the idea that "less is more."

Barriers to change

Desiring certain reforms and making them happen are very different matters. The case for the desired reforms presented above has strong support in the research literature. On the other hand, the means by which these reforms can be attained is not so certain. There are many barriers to change and the strategies for overcoming them are not fully understood.

Among the barriers to change are the beliefs and values on the part of everyone involved including the teachers, administrators, the community, and reformers themselves. A certain amount of consensus is needed for reform efforts to be mobilized effectively over the years of time required. The more diverse these beliefs and values are, the more difficult is change. Even if the reformers should agree on the matter of goals and the nature of learning and teaching, there is still the need for consensus regarding the means for reaching this new vision of education. Given the political context of reform efforts, it is clear that the lack of consensus among the public at large is a barrier to reform as well.

Diverse values and beliefs among teachers and administrators also are a barrier to change. A constructivist view of learning and teaching is far from universal among professionals in the schools. Furthermore, many professionals place socialization goals above intellectual development goals (Stake & Easley, 1978).

Similarly, student expectations are a barrier. Many students, often those who are most successful in the current system, resist changing from a predictable process in which they know how to succeed to one which fosters intellectual development in a context of some uncertainty, problems with multiple solutions and a lack of specific directions as to what to do.

Even if there is an adequate consensus vision of what education should be on the part of everyone involved, change is not assured. Change is not easy; in particular, changes in the roles of people are difficult. It is not easy for teachers to learn the new roles required of those who want to foster a classroom environment in which students take responsibility for their own learning. It is not easy for students to overcome passivity and learn the needed role as a responsible and proactive learner.

All of the barriers described above exist within powerful institutional and cultural constraints. While the problems of bureaucracies, limited budgets, assessment practices and rigid regulations are well recognized, the cultural constraints are at least as powerful, but often less visible. The commonly accepted values, beliefs and practices of the society found within a given school or community form a common culture which typically is a powerful constraint to change.

There are many barriers to educational reform; change clearly is difficult. It requires resources, commitment, knowledge and skills. Moreover, success depends upon applying them in the correct setting with appropriate timing. It is this approach to change which needs further attention.

The Process of Change

The process by which change occurs varies greatly from one setting to another and from one time to another. Although certain generalizations appear to apply to successful change endeavors, there is no particular set of processes (plural) to apply to ensure success. The overall process (singular) varies greatly but there are some important understandings that seem important to success.

First, a systemic outlook is essential (Anderson, 1990; Fullan and Stiegelbauer, 1991). All efforts to introduce new instructional approaches, new curriculum materials or instructional goals demand such actions as inservice education for teachers, discussions with parents to develop consensus on goals and new directions, and leadership from administrators. Change requires attention to the subcultures of students, schools and communities. None of these actions by itself is sufficient. All of them together may not work if initiated without consideration for how they interact with each other.

As a result, systemic thinking is not just something to include in one's approach to educational reform; it is a way of thinking that must be applied to the situation to begin to understand it well before even suggesting means of bringing about change.

Using systems thinking for reform. Effective application of systems thinking to educational reform requires a disciplined approach.

> "The essence of the discipline of systems thinking lies in a shift of mind:
> * seeing interrelationships rather than linear cause-effect chains, and
> * seeing processes of change rather than snapshots.

> "The practice of systems thinking starts with understanding a simple concept called 'feedback' that shows how actions reinforce or counteract (balance) each other. It builds to learning to recognize types of 'structures' that recur again and again:..." (Senge, 1990, p. 73).

Understanding the situation systemicly requires attention to psychological, philosophical, socio-cultural and subject-matter perspectives (Anderson, 1992). It requires attention to organizational and political considerations. Actions taken at the national, state, district, school and classroom levels, for example, can interact to support change in a common direction, or they can counteract each other in such a manner that change is defeated. And even though all actions taken are complementary, there is the possibility that the omission of some particular action or actions could stall what would otherwise be a successful reform effort. A vision of what should be must be combined with a systemic process of working toward that vision.

Second, positive and lasting change requires empowerment of teachers and an opportunity for them to develop their professional competency. They must come to view their role as helping students construct meaning. Such substantial change demands that teachers be empowered to develop their professional competencies. In effect, teachers need to construct new understandings of their role and develop the ability to incorporate these new understandings into their actions as teachers and to become reflective learners themselves. These new changes need to be reaffirmed by the development and use of constructivist assessments to support the changes in materials and teacher development.

Third, such fundamental and far-reaching changes imply significant changes in the culture of the schools. It means new roles for teachers, students, parents, and administrators. More collaboration among teachers and new responsibilities, for example, may emerge as important elements in this changed culture. Such changes demand a systemic outlook that causes individuals to reassess values and beliefs pertaining to education.

A Learning Organization. True reform will have occurred when the schools involved are not only reformed but have become reforming institutions, i.e., they are schools in which continuous progress and improvement are part of the "fabric of the place." In his explication of organizational theory, Senge (1990) refers to such an organization as a "learning organization". In his analysis, there are five "disciplines" of the learning organization, with the "fifth discipline"--the cornerstone of the others--being the systems thinking discussed above. The four others are listed below along with brief descriptions.

PERSONAL MASTERY--"... the discipline of continually clarifying and deepening our personal vision, of focusing our energies, of developing patience, and of seeing reality objectively." "But surprisingly few organizations encourage the growth of their people in this manner." (Senge, 1990, p. 7)

MENTAL MODELS--"... deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take áction." (Senge, 1990, p. 8) In a learning organization considerable effective effort is devoted to developing shared mental models among its members.

BUILDING SHARED VISION--a key idea about leadership that has been around for a long time. "When there is a genuine vision (as opposed to the all-too-familiar 'vision statement'), people excel and learn, not because they are told to, but because they want to." (Senge, 1990, p. 9)

TEAM LEARNING--"When teams are truly learning, not only are they producing extraordinary results but the individual members are growing more rapidly than could have occurred otherwise." "Team learning is vital because teams, not individuals, are the fundamental learning unit in modern organizations. This is where 'the rubber meets the road'; unless teams can learn, the organization cannot learn." (Senge, 1990, p. 10)

There are many similarities between these four disciplines of Senge and principles espoused by Fullan. Senge's "fifth discipline" -- systems thinking -- adds a new dimension to the discussion. This aspect will influence the analysis employed in the research as described in a later section of this paper.

There are some obvious similarities between aspects of the curriculum reforms under consideration in this review and the characteristics of a "learning organization." This similarity is not surprising; in both cases human learning--in an individual and collective sense--is the core of the matter. In one case it is the learning of students and in the other case the learning of an entire community of professionals, other staff and students.

Delving deeper into the characteristics of a learning organization is beyond the scope of this paper, but it would be difficult to overemphasize their importance for the topic at hand. Becoming a "learning organization" may be the ultimate solution to the school or district wanting to foster long-term curriculum reform.

Implications of the Research Literature for the Project

Although it may not be reflected fully in the portions cited above, the literature review conducted as part of this research project has a number of important implications for the research being conducted. It became clear that in developing the conceptual framework for this set of case studies of curriculum reform, and in selecting the schools for these cases, that the following are particularly significant implications.

1. One should not expect school sites with fully implemented reforms to serve as the subject of study for these case studies. The process of reform is long enough and the efforts have been initiated recently enough that it is unrealistic to expect that examples of fully installed reforms are ready for study. Case studies of reform are valuable and available, but of necessity, they almost certainly will still be in process to some extent.

2. It is essential that these sites be studied from a systemic perspective.

3. It is essential that these sites be studied from multiple perspectives, i.e., that they be examined through the eyes of a philosopher, psychologist, sociologist, anthropologist, political scientist, organizational specialist and subject-matter specialist. The complexity of the situations under study demands these multiple perspectives.

The research reviewed also suggests numerous important questions to pursue in the case studies. The results of the literature review are reflected in the design of the research described below.

DESIGN OF THE CASE STUDIES

Selection of Sites for Case Studies

Although one would not expect to find fully developed examples of curriculum reform in mathematics and science in which the full range of reforms are in place and functioning as intended, the intend has been to find sites for study in which the desired reforms are as fully initiated as possible. Based on the literature review, sites were sought in which as many as possible of the following major reforms were in place to the fullest possible extent (not in any priority order).

1. Enabling <u>all students</u> to learn to think is an educational goal that extends across the disciplines with particular attention in the subject areas of science and mathematics.

2. Teachers have a constructivist conception of their role; rather than viewing students as passive recipients of information, they focus on helping students construct understanding of concepts for themselves.

3. The related approach to the curriculum often described as "less is more" is practiced.

4. Instead of presenting isolated facts, major attempts are made to focus on major themes of the subject matter and foster an integration of knowledge across the disciplines.

The cases sought were schools having as many as possible of these reforms firmly in place with evidence of positive outcomes for students.

The Research Questions

Among the prominent research questions are ones pertaining both to the substance of the reforms and the means by which the reforms were put in place. With respect to the substance of the reforms attention is being given to both the content of the curriculum and the instruction by which students acquire it. With respect to the means by which the reforms are put in place, particular attention is being paid to systems thinking and the overall patterns of reform activities. Are successful reform sites appropriately described as "learning organizations?"

The substance of reform. The following questions are among those being addressed with respect to the curriculum reforms themselves.

1. How are the sites defining their purposes and goals of reform with respect to students, teachers and the rest of the system?

2. What changes have occurred in the content of instruction?

3. What changes have occurred in the means of instruction, i.e., how are teachers fostering students' ability to construct desired learning outcomes?

4. What has been the impact on student learning and what can be inferred from positive results about various ways of teaching science, mathematics, and higher order thinking?

5. How "deep' are the changes; i.e, have the beliefs of students, parents and teachers changed?

6. To what extent and how is the learning and teaching of thinking skills being transferred across disciplines?

The means of reform. Attention also is being directed to study of how people got to where they are. This investigation will include looking for patterns of support throughout the system and examining how people monitor their progress toward desired goals.

1. What are the mechanisms for change?

2. How do implementation efforts play out in classrooms; i.e. what happens in classrooms when teachers embrace the spirit of the reforms espoused by the various national groups?

2. How are sites developing high quality content that meets the needs of their full range of students?

3. How are sites developing teachers' abilities to use a constructivist way of teaching?

4. What are the dynamics of change as viewed from a teaching and learning perspective among (a) students, (b) teachers and (c) the rest of the system?

5. How are sites working out the trade-offs related to financial and expertise resources?

6. To what extent has the process of reform been top-down, bottom-up, or some combination of the two?

7. What are the means of system support? To what extent and in what ways are the system support strategies congruent with a constructivist view of teaching and learning?

8. To what extent does the approach to change at the sites reflect systems thinking?

Conceptual Framework

Time perspective. The conceptual framework for this research is based on looking at a "slice" of the present (portions of one academic year) to understand (1) the past from which it came, (2) the present (in terms of influences, results and dilemmas), and (3) the perceptions of future destinations held by the various people involved. As a result the research questions stated above must be expanded upon to give a form such as the following.

* What are the past patterns of school practice from which the current practices emerged?

* What is the nature of current school practice?

* What is the future which the various actors envision as their intended destination?

Influences, results and dilemmas. To understand more of how changes over time have and are occurring, it is necessary to examine the dynamics of the situation including the following.

* What influences (e.g., pressures, supports or barriers) have affected these reforms?

* What have been the results of these reforms?

* What dilemmas have arisen for the various actors in these reform efforts? (Romagnano, in press).

These questions about influences, results and dilemmas encompass at least the following dimensions: (1) personal, (2) interactional, (3) contextual, and (4) historical.

Comparison of perspectives. What are the perspectives of the following at each site and how do they compare: students, teachers, administrators, policymakers, and parents? How does the reform as defined at each site map onto reform ideas as defined by (1) professional groups at all levels, and (2) the public in general?

Systems thinking. How can a systems approach to analyzing these reforms help in understanding the changes?

Critical Events

An important aspect of this case study research is identifying critical events that embody or illustrate the reform effort (whether successful or unsuccessful) as defined by (1) the policies and actors at the site under study or (2) the research literature or recommendations of national professional reform groups. The former emerge empirically from study of the sites themselves, while the latter are sought at each site within categories defined by the professional literature. Establishing these latter categories is essential to assure that at each site data needed for cross-site and cross-discipline analysis is obtained.

Among the types of events sought are the following:

Classroom events as defined by some aspect of the curriculum, pedagogy or time.

School events (other than classroom events) within committees, faculty meetings or meetings with constituents such as parents, school boards, or state policymakers.

Policy events regarding the curriculum, instructional materials, teaching practices, school organization or goal statements.

Because of the importance of subject-matter considerations within this research, all of the above events will be examined along two dimensions: discipline specific and non-discipline specific.

In seeking out the critical events which the literature indicates are important, the following guides to observation, questioning and analysis will be used:

Student goals and expectations as exhibited in intended and actual learning outcomes,

Teacher professionalism as reflected in professional development activities and participation in professional work such as curriculum development.

Vision as indicated by changes in school curricula or pedagogical practices, school routines or daily operations, and statements of vision.

Curriculum, instruction and assessment design including the degree of complementarity of these three.

Changing roles of students, teachers, administrators and parents, with attention to their responsibilities and the interrelationships of these roles.

Resource allocation, including both financial allocations and the expenditure of professional time.

Means of expanding the reform to additional individuals and groups, or portions of the curriculum.

The critical events identified will be analyzed in terms of three types of influences.

Personal: influences based in the knowledge and beliefs of the individual actors involved in the reform effort as these beliefs and knowledge relate to such matters as the discipline, teaching, learning, school and students.

Interactional: influences based in the interactions of people in classrooms or other settings.

Contextual: influences arising in the social, cultural, structural, organizational, political, or historical context.

Data Collection

Although additional data is being gathered through printed materials and telephone interviews before, between and after the

site visits, the bulk of the data collected is being acquired through site visits conducted during the 1992-93 academic year. This data will be acquired primarily through (1) observation of classes and other school events, (2) interviews with individuals such as students, teachers and administrators, and (3) analysis of documents. The specific data collection protocols are derived from the research questions, conceptual framework and critical events framework described above.

The data collection, data analysis and writing of results are not chronologically linear. The data collection protocols are at some points altered to reflect the results of the initial data analysis which is conducted systematically and regularly during and between site visits.

Analysis

Analysis is being conducted at three levels: within individual sites, across sites within each of the disciplines, and across all sites. Analysis at all three levels is proceeding in parallel, moving in and out of the three levels. Analysis occurs during site visits as well as between visits with the results of the initial analyses influencing the subsequent data collection.

The goals of the analysis are to produce descriptive "snapshots" and "motion pictures" -- and interpretive portrayals -- at and among all three analysis levels. Matrices reflective of the research questions, conceptual framework and critical events format described above are being developed to use in the data analysis as well as for reporting.

A particular analysis strategy being developed is one that uses the systems thinking tools provided by Senge.

Systems Thinking Applied to Curriculum Reform

The use of systemic frameworks for analyzing organizations is getting considerable attention beyond what it has received in the educational field. Scholars in other arenas are attending to "systems thinking" and studying organizations from a perspective that attends to the organizations capability to learn and grow (Senge, 1990). This more encompassing systems perspective provides the cohesive conception needed for a greater understanding of the processes of reform.

What is systems thinking? In his treatise on organizational theory, Senge presents systems thinking as not only a conceptual framework for understanding organizations, but a body of knowledge and collection of tools to use in influencing a system. As the "fifth discipline" in his analysis of the "learning

organization", it is the cornerstone of all the other "disciplines" in his characterization of dynamic and effective organizations.

Systemic structures. A beginning point for a deep understanding of systems thinking is understanding systemic structures.

> "The term 'structure,' as used here, does not mean the 'logical structure' of a carefully developed argument or the reporting 'structure' as shown by an organization chart. Rather, 'systemic structure' is concerned with the key interrelationships that influence behavior over time. These are not interrelationships between people, but among key variables, such as population, natural resources, and food production in a developing country; or engineers' product ideas and technical and managerial know-how in a high-tech company." (Senge, 1990, p. 44)

In educational settings, these interrelationships exist among curriculum content, testing programs, and teacher decision-making in a curriculum reform endeavor; or among learning and teaching theories, student values, teacher beliefs and administrative leadership in a school.

Systems complexity. Within a given system, e.g., a given school, these complex interrelationships produce a dynamic that in a way has a life of its own. As Meadows (as quoted in Senge, 1990, p. 43) notes, "The system causes its own behavior."

The complexity of such systems is the result of both the many details and the dynamics involved. In particular, this dynamic complexity is relevant to understanding educational situations and provides a perspective from which the data in the case studies will be analyzed.

> "The second type is dynamic complexity, situations where cause and effect are subtle, and where the effects over time of interventions are not obvious. Conventional forecasting, planning, and analysis methods are not equipped to deal with dynamic complexity. Mixing many ingredients in a stew involves detail complexity, as does following a complex set of instructions to assemble a machine, or taking inventory in a discount retail store. But none of these situations is especially complex dynamically.
>
> "When the same action has dramatically different effects in the short run and the long, there is dynamic complexity. When an action has one set of consequences locally and a very different set of consequences in another part of the system, there is dynamic complexity. When obvious interventions produce nonobvious consequences, there is

dynamic complexity. A gyroscope is a dynamically complex machine...." (p. 71)

Putting the new understanding to work. The application of systems thinking to curriculum reform is not in finding the solutions that will solve the problem in a given setting. The situations are too complex and achieving success is an art. Systems thinking is an aid to this art. It can help in understanding the dynamic complexity of a given situation. It can pinpoint key interrelationships. It can help anticipate the unintended consequences of proposed actions.

> "The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity..... "Unfortunately, most 'systems analyses' focus on detail complexity not dynamic complexity. Simulations with thousands of variables and complex arrays of details can actually distract us from seeing patterns and major interrelationships. (Senge, 1990, p. 72)

> "The bottom line of systems thinking is leverage--seeing where actions and changes in structures can lead to significant, enduring improvements. Often, leverage follows the principle of economy of means: where the best results come not from large-scale efforts but from small well-focused actions. Our nonsystemic ways of thinking are so damaging specifically because they consistently lead us to focus on low-leverage changes: we focus on symptoms where the stress is greatest. We repair or ameliorate the symptoms. But such efforts only make matters better in the short run, at best, and worse in the long run. (Senge, 1990, p. 114)

> "It's hard to disagree with the principle of leverage. But the leverage in most real-life systems, such as most organizations, is not obvious to most of the actors in those systems. They don't see the 'structures' underlying their actions. (Senge, 1990, p. 114)

> "Systems thinking finds its greatest benefits in helping us distinguish high- from low-leverage changes in highly complex situations. In effect, the art of systems thinking lies in seeing through complexity to the underlying structures generating change. Systems thinking does not mean ignoring complexity." (Senge, 1990, p. 128)

The leverage points are what is being sought via the analysis -- both the leverage points for these particular sites and possible generalizations about leverage points.

The implications of this way of thinking are of major consequence when considering curriculum reform. The apparent

educational problems may well not be the real problems. The apparent causes of the problems are not likely to be the real causes. The obvious solutions are not likely to be effective and in addition they probably will have undesirable side effects. Using the data, analyses must be done to test this idea using the tools described below.

Specific tools of systems thinking. A specific tool used in systems thinking is the application of what Senge (1990) calls systems archetypes to a given setting to identify key interrelationships. These archetypes, with labels such as "limits to growth" and "shifting the burden," are an aid for seeing interrelationships within the whole. Their purpose is to help identify structures and find the leverage, something that is hard to do in the midst of the crosscurrents and pressures of real-life situations. They have been used in our application of the Senge tools to curriculum reform, for example, to identify:

1. limits to the move toward an applications-oriented science curriculum,

2. the side effects of certain short-term solutions to the problem of declining test scores,

3. potential erosion of commitment to long-term goals with the application of some short-term solutions to such goals as an increase in higher order thinking, greater gender equity and more hands-on learning,

4. processes which reinforce unequal allocation of resources to competing educational programs, and

5. potential depletion, rather than wise management, of the limited resource of teacher time in some programs of educational reform.

6. limits to how far teacher changes can go without changes in student responsibility and engagement in learning.

The application of these tools provides context-specific information of value in specific situations faced by practitioners and policy-makers initiating reform, or by researchers designing their research.

Scope of the analysis. In the original design of this research, the analysis was expected to be (1) within sites, (2) across sites within a discipline, and (3) across all sites. Given the current uncertainty as to the scope and duration of our funding, it is not clear how far the analysis will extend beyond the within site stage.

Reporting

Reporting is expected to be built to a considerable extent upon "stories" or vignettes that portray descriptions and interpretations derived from the analysis. The stories will be used to answer research questions and to portray the patterns found in the analysis. The matrices described above will be used to support the stories and reflect the analysis.

FUTURE DIRECTIONS

What has been presented here is a progress report for an ongoing project. As the analysis of these three cases is pressed toward completion following the 1992-93 school year -- and plans are made for additional research during 1993-94 as funding permits -- interaction with persons conducted related research is welcomed.

BIBLIOGRAPHY

Anderson, R. D., Anderson, B.L., Varanka-Martin, M.A., Romagnano, L., Bielenberg, J., Flory, M., Mieras, B., Whitworth, J. (1992). Issues of Curriculum Reform in Science, Mathematics and Higher Order Thinking Across the Disciplines. Boulder CO: University of Colorado, School of Education. 151 pages.

Anderson, R.D. (1992). Perspectives on complexity: An essay on curricular reform. Journal of Research in Science Teaching, 29(8), 861-876.

Anderson, R.D. (1990). Policy decisions on improving science education: A cost-effectiveness analysis. Journal of Research in Science Teaching, 27(6), 553-574.

Fullan, M.G. & Steigelbauer, S. (1991). The New Meaning of Educational Change. New York: Teachers College Press, Columbia University.

Romagnano, L.S. (in press). The Dilemmas of Change: A Tale of Two Mathematics Teachers. Portsmouth, NH: Heinemann.

Senge, P. (1990). The Fifth Discipline: The Art and Practice of the Learning Organization. New York: Doubleday.

Stake, R.E. & Easley, J.A. (1978). Case Studies in Science Education. Urbana-Champaign, IL: Center for Instructional Research and Curriculum Evaluation and Committee on Culture and Cognition.